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USE OF NUCLEAR POWER SOURCES IN OUTER SPACE

Working paper submitted by the Russian Federation

It is generally accepted that in order to solve the problem of radiological safety of spacecraft carrying nuclear power sources (NPSs), it is important to study collisions of spacecraft carrying NPSs with space debris. The radiological consequences of such collisions are determined by the altitude of the NPS-carrying spacecraft's orbit, the circumstances of the collisions, the mechanisms of disintegration of the NPS, the possibility of descent from orbit and the aerodynamic disintegration of the NPS or its components on descent through the atmosphere.

Bearing in mind the view of the Subcommittee regarding the need for further investigation of the problem of collisions between NPSs and space debris and for publication of the results of such investigations, the Russian Federation is submitting a working paper giving the preliminary results of calculations carried out in 1991 as part of the Federation's overall programme to investigate the safety of space NPSs.

The paper considers possible collisions with space debris by the nuclear power reactors (NPRs) launched into space between 1970 and 1988 and located in 700-1,000 km orbits (see the working paper by the USSR of 26 February 1990, A/AC.105/C.1/WG.5/L.24/Add.2).

Collision conditions (velocity, angle) were selected for the collision of a fuel element assembly with space debris in the form of steel fragments with a mass of 0.25 kg and a linear dimension of 4 cm, and with a mass of 1.4 kg and a linear dimension of 7 cm. A study was made of the numerical modelling of a one-dimensional impact load applied to the laminated structure of a fuel element assembly consisting of 37 cylindrical fuel elements with annular

beryllium reflectors and uranium-molybdenum alloy fuel pellets. The fuel elements were fixed in a housing which also contains components of the drive mechanism for ejecting the fuel element assembly from the reactor vessel. The impact of a 0.25 kg fragment with a velocity of 7 km/sec and of a 1.4 kg fragment, with a velocity of 1 km/sec on the steel components of the drive mechanism in the fuel element assembly was calculated. The initial parameters for the trajectory of the fuel element assembly before the collision were taken from data for the COSMOS-1900 and COSMOS-1932 satellites.

The collision of a fuel element assembly with a 0.25 kg fragment may be expected to lead to disintegration of the fragment and the steel components of the drive mechanism into particles of the order of 20 micrometres in size. The fuel element assembly with the housing will continue in flight after being subjected to a retarding impulse of 47 m/sec. In the case of collision of a fuel element assembly with a 1.4 kg fragment, the fragment, the drive mechanism components, and to some extent the housing and the end portions of the fuel elements may be expected to disintegrate into particles of the order of 20 micrometres. The individual fuel elements will continue in flight after being subjected to a retarding impulse of 28 m/sec. The retarding impulses for the fuel element assembly and for an individual fuel element are calculated in accordance with the direction cosines of the velocity vector of the fuel element assembly's flight path at the time of the collision.

The change in flight trajectory parameters and the lifetime of the objects after the collision (see table) were calculated for two models of the atmosphere: GOST 25645.115-84, which applies in the Russian Federation, and CIRA-86 with average solar activity indices of $F_{10.7} = 106$ and a geomagnetic perturbation index of $K_r = 2.667$. The ballistic coefficients of the objects after the collision are 503 kg/m^2 for the fuel element assembly with the housing and 116 kg/m^2 for an individual fuel element.

With a minimal lifetime of the objects after the collision of more than 100 years, the activity in the reactor fuel will be determined by the caesium 137 content, and amounts to:

For the fuel element assembly - lifetime 450 years and activity 0.0017 curie;

For an individual fuel element - lifetime 200 years and activity 0.015 curie.

Thus, the objects after the collision - a fuel element assembly with housing and individual fuel elements - will, with aerodynamic dispersion occurring in the dense layers of the atmosphere, present practically no radiation danger to individual members of the population or to the environment. The only possible consideration would be chemical pollution of the soil by uranium and beryllium, the level of pollution by which is determined by the aerodynamic disintegration of the fuel element assembly structure and of individual fuel elements.

Entry of the fuel element assembly and of individual fuel elements into the atmosphere after the collision will result in disintegration of the steel casings of the fuel elements and the housing at altitudes of 88-87 km, accompanied by release of the fuel pellets and the annular beryllium reflectors. The subsequent free fall of the fuel pellets ends with their melting in the altitude range 86-85 km, with the formation of an extended particle source 150 km long. Calculation of the further movement of the fuel particles and the change in their dimensions by the Monte Carlo method, taking into account fragmentation of the melted material, evaporation and the chemical reactions of the uranium with the oxygen in the air, yield a probable particle spectrum with final dimensions in the 60-880-micrometre range deposited at altitudes of 64-18 km, with an overall ballistic extent of the cloud of around 400 km along the descent trajectory.

The fuel particle distribution by size is described by a logarithmic normal law, which yields an average size of 225 micrometres. The maximum density of particle fallout is 40 g/km^2 for a mass in the fuel element assembly of 30 kg of uranium 90 per cent enriched with uranium 235. The surface contamination of the soil with uranium, 0.04 mg/m^2 , can yield a volume content in the cultivated soil layer of not more than 0.2 mg/m^3 , insignificant in comparison with the natural uranium content of the soil, which is of the order of 1.5 g/m^3 .

Aerodynamic disintegration of the annular beryllium reflectors, whose total mass is 4.15 kg, takes place at altitudes of 77-67 km over a section of the trajectory 200 km long. The probable range of final particle sizes is 1.175-8.83 mm for an altitude of 77 km and 0.615-3.32 mm for an altitude of 67 km. The density of beryllium fallout at the earth's surface will not exceed 0.05 mg/m^2 , which corresponds to a volume content in the cultivated soil layer of 0.5 mg/m^3 , and is lower than the natural beryllium content in the soil, which is estimated as being at the 4 g/m^3 level.

Thus, fallout of particles of toxic materials from a fuel element assembly (uranium and beryllium) following aerodynamic disintegration will not have chemical consequences.

Subsequent studies of issues involving the collision of NPSs with space debris are aimed at developing computer software for two-dimensional impact loading at high collision velocities in combination with analytical engineering methods. This will afford more realistic numerical modelling of collisions, a reduction in the computer time spent on calculations and a substantial increase in the number of simulations, among which simulations of collisions with radiological and chemical consequences are not excluded.

Lifetime of objects without collision and after collision

Initial orbit of fuel element assembly, km	Lifetime of fuel element assembly without collision, years			Mass of fragment, kg	Impact velocity, km/s	Retarding impulse, m/s	Object after collision	Life after collision, years	
	Atmosphere GOST 25695-115-84	Atmosphere CIRA-86	Atmosphere CIRA-88					Atmosphere GOST 25695-115-86	Atmosphere CIRA-88
765 719	1 000	1 200		1.4	1.0	20	Individual fuel element	250	200
977 937	10 300	10 000		1.4	1.0	20	Individual fuel element	2 300	2 200
765 718	1 400	1 200		0.25	7.0	47	Fuel element assembly with housing	600	450
977 937	10 500	10 000		0.25	7.0	47	Fuel element assembly with housing	7 000	6 500